NASA TECHNICAL TRANSLATION NASA TT F-15,868

UTILIZATION OF WIND ENERGY IN DENMARK

No author

Translation of "Utilisation de l'énergie du vent au Danemark", La Technologie Moderne, Vol.35, No. 13-14, July 1-15, 1943, pp. 106-109.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. SEPTEMBER, 1974

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TT F-15,868		
4. Title and Subtitle UTILIZATION OF WIND ENERGY IN DENMARK		5. Report Date September, 1974 6. Performing Organization Code
7. Author(s) No author		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Utilisation d l'énergie du vent au Danemark", La Technologie Moderne, Vol. 35, No. 13-14, July 1-15, 1943, pp. 106-109.

16. Abstract

This article presents a review of the use of wind energy in Denmark during World Wars I and II. It presents statistical data on other energy sources and compares costs of all types of energy. Some technical discussion of the Lykkegaard 5.5 m diameter mills and F.L.S. 17.5 m diameter mills is given.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	

UTILIZATION OF WIND ENERGY IN DENMARK [1]

No author

Development of windmills in Denmark

Denmark has been the first European country to direct /106* its attention to the rational usage of wind energy. In 1891, the Danish government requested Professor La Cour to set up a test installation at Askof. For the first time, a four-bladed mill wheel was coupled to an electric generator, so that the energy produced could be stored in batteries; this corrected the main fault of wind-powered engines – their lack of constant output. The Askof installation gave good results, and was soon duplicated in a great number of models, especially through the impetus of the Lykkegaard company of Ferritslev (Fuenen Island), which built installations according to La Cour's plans.

Use of the wind experienced its first advancement during World War I, when coal and liquid fuels had become unobtainable. A large number of mills were constructed in Denmark at that time, both as sources of mechanical power and for the production of electricity. The first ones were still the La Cour mills, but toward the end of the war there appeared mills which were better designed from an aerodynamic point of view, particularly the Agricco mills (Figure 1) due to

* Numbers in the margin indicate the pagination of the original foreign text.

Dr. Vinding; these spread not only through Denmark, but also abroad. During this period, Dr. Vinding collaborated with J. Jensen in the study of a three-phase installation with an asycnhronous generator feeding a power distribution grid. A three-phase generator with a commutator, which could match changes in mill speed, was also studied, but nothing was published about it. Slightly later, but in the same line of thought, Professor Larsen proposed the use of DC mills, with the energy transmitted to the power grid via a rotating DC-AC converter. This approach was too complicated and expensive, however, for the 30-35 kW (maximum) installations which were available at that time.

Utilization of wind energy has again become a necessity for Denmark with the outbreak of the present war. The Lykkegaard Company has built a series of 30 to 35 kW aeromotors for the use of the small power companies wihch abound in Denmark. These small companies normally produce their power from diesel engines, and the change-over of these engines to producer gas did not completely solve the fuel crisis. The good results obtained with the Lykkegaard mills soon encouraged other manufacturers to undertake bolder designs. In particular, the F.L. Smidth Company of Copenhagen built very modern-looking mills known /107 as the F.L.S. aeromotors, using the designs of its director at that time, Gunnar Larsen, who is now Minister of Transport. Some ten of these systems are in service in Denmark and are giving good results.

The development of wind energy in Denmark can be followed from the diagram of Figure 2, which shows the increase both in the number of installations and in the electric energy produced during the period 1940-1941.

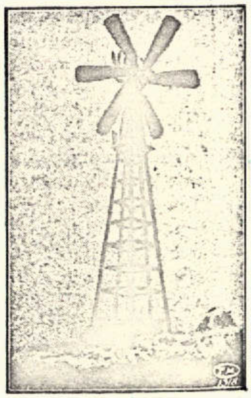

Figure 1. Agricco windmill

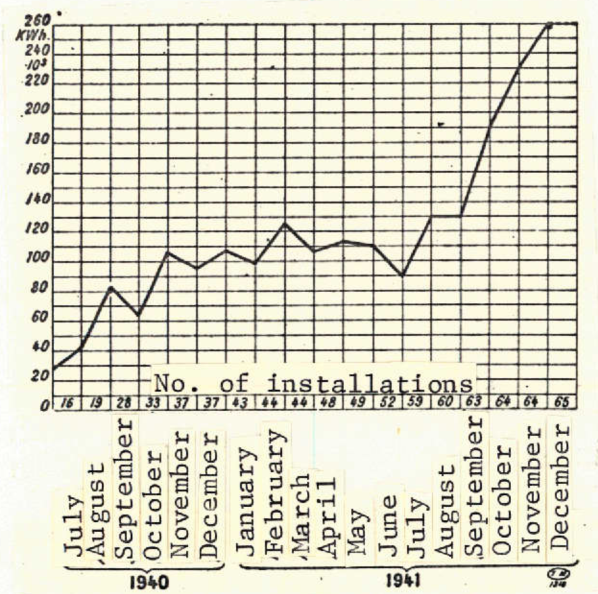

Figure 2. Increase in number of installations and energy produced in 1940-1941.

Total production in 1941: 1,780,200 kWh.

The most interesting installations are described below.

Importance of wind power to the Danish economy

It is useful to emphasize at the outset the peculiar characteristics of energy distribution in Denmark. The 3.7 million inhabitants of this country subsist for the most part by agriculture, so that aside from the capital, Copenhagen, there are very few large cities. This distribution of population determines the character of power distribution. There are large generating stations only at Copenhagen, while the small towns and the countryside are supplied by a very large number of small plants, both municipal and private. In 1937-1938, there were a total of 487 public enterprises, of which only 13 each produced more than 5 million kilowatt-hours annually. By themselves, these 13 stations produced 75% of the total consumption of 660 million kWh (325 million for Copenhagen alone).

There were also a large number of private installations, 314 of which were greater than 30 kW, and about 1,000 of which had a total power of 4,000 kW.

These numbers point up a scattering of production capacity which probably can be found nowhere else in Europe.

Denmark has neither large waterfalls nor coal mines, so production of electricity depends entirely on importation of foreign fuels. (Imports in 1936-1937: coal, 370,000 metric tons; heavy oil, 520,000 metric tons.) Contributions of the various energy sources are as follows: coal, 75%; heavy oil, 20%; waterfalls, 4%; miscellaneous, 1%.

There are in addition very many DC power grids supplied either by small local DC plants or by sub-stations with rotating AC-DC converters. Although 79% of the power is supplied by AC generators (and 21% by DC generators), it is estimated that only 60% is distributed as AC (and 40% as DC).

The almost complete cessation of imports in 1939 placed the Danish producers in a difficult situation. The small plants were joined together as much as possible and connected to distribution grids to reduce fuel consumption by better utilization. The large power stations mixed their coal with peat, of which there are adequate quantities in Denmark. The small plants converted their diesel engines to producer gas, but at the price of a decrease in power and a greater difficulty of operation.

Since there were already aeromotor installations,whose production was negligible, it is true, electricity producers were induced to consider usage of wind power on a wider scale, and from 1940 a number of mills were constructed. It is interesting to note that at this time the authorities delivered the necessary authorizations only in those cases where rapid amortization could be expected. It seemed then that the war would be short, and the installation of mills would be only a temporary measure: they were to disappear as soon as fuel importation would again be possible. The pure and simple connection of small installations to the power grid was even suggested because, with the rapid amortization of the mills, the cost price per kilowatt-hour was definitely higher than that for the grid. These hopes were not realized, however. It could not be expected that Denmark would be able to obtain foreign fuels in unlimited quantity and at a normal price for a long time. Besides, connection of widely scattered consumers to the grid required construction of electric lines which would entail very heavy financial burdens even if their construction were possible despite the present scarcity of material. In the last analysis, this general electrification would lead to increased consumption of coal, and even to the necessity of expanding thermal stations which were at the limit of their production.

The Danish authorities were thus forced by events to modify their point of view, and to consider use of windmills in the post-war period, which would considerably reduce the burdens of amortization. Furthermore, conditions in Denmark were very favorable for the establishment of small autonomous windmill power plants. A large part of the rural lines were DC, so one could use low-power wind-driven DC plants whose construction would offer no technical difficulty to speak of, unlike construction of high-power AC plants. Auxiliary installations, required for periods of calm, were already in place, since most of the existing plants had diesel engines adapted for producer gas, and banks of storage batteries. Unlike other approaches, each kilowatt-hour produced by the wind corresponded to an overall saving of fuel.

The only apprehension experienced was toward the possibility of insufficient reliability of the back-up stations. It will be seen below that there are machines of tested construction, to which operating lifetimes of 12 to 15 years can be assigned, so that it is not rash to provide for their amortization over ten years. The cost price of the energy produced was thus much less than originally expected. These more favorable financial conditions allowed a rapid increase in the number of installations and in the power produced, as shown in Figure 2 (production in December, 1941, was nearly ten times that of July, 1940). However, 75% of the total consumption was still produced by

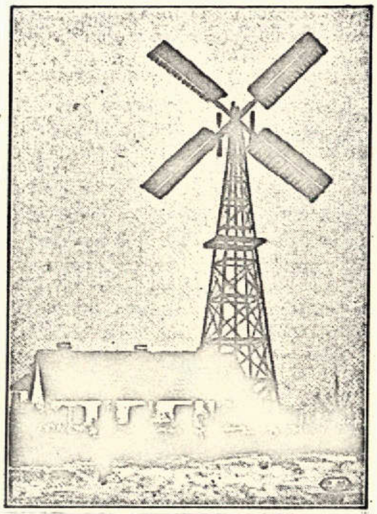

Figure 3. Retractable-blade aeromotor 18 meters in diameter.

Power: 30 kW for wind velocity of 10 m/sec

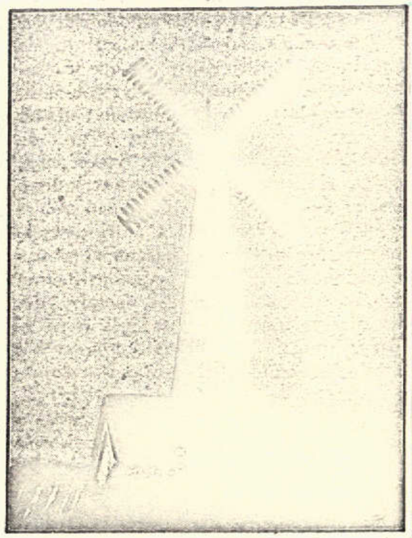

Figure 4. The same aeromotor with blades retracted by high wind

coal, and production by wind does not seem to have been intended to exceed at most 15% of the total. To increase this proportion, proven aeromotors with power greater than 200 kW would have to be available, expecially for supplying small towns: such technology must still be created, and the economics are still being debated.

Description of installations in Denmark

The largest installations have been built by the Lykkegaard and F.L. Smidth companies, whose machines are very different.

The Lykkegaard machines are classic mills derived directly from La Cour's plans. The "Aurora" type, with maximum diameter of 5.5 m, can scarcely be considered for low-power generating plants. In contrast, the "Mammoth" type, with retractable blades (Figures 3 and 4), can be built as large as 18 or even 20 m, which corresponds to a rather large power.

This four-bladed aeromotor, constructed along the lines of the classic Dutch mills, is mounted at the top of a metal pylon and drives a dynamo on the ground by means of a vertical shaft and bevel gears. Each blade is composed of a number of retractable flaps mounted along a central wooden beam bolted to a cast-iron hub. The various flaps are made of treated wood, and move on hinges parallel to their long sides; the flaps on a single blade are interconnected by a system of rods running along the central beam. The position of the flaps on the four blades can be adjusted from the ground by means of a control system which runs through the hollow shaft of the wheel. When the wind is weak, the flaps are set next to each other to form a continuous surface (Figure 3), and the mill behaves like a fixed-blade mill: i.e., its velocity and power increase with wind velocity. As soon as the speed of rotation reaches a predetermined value, the flaps swing on their hinges under the effect of a centrifugal governor, and the blades appear as in Figure 4. Their effective surface decreases and their velocity stops increasing.

The only electrical equipment is an anti-compound generator and a self-closing circuit breaker. The voltage is held sufficiently constant because it operates in parallel with a bank of storage batteries. The installation does not operate entirely automatically. In particular, the state of charge of the batteries must always be checked.

These aeromotors with retractable blades start well, and can supply current as soon as the wind velocity reaches 4 to 4.5 m/s. They reach a top power of 30 kW at a wind velocity of 10 to 11 m/s. Figure 5 shows the power output as a function of wind velocity. This power is limited to 30 kW by the automatic retraction of the flaps. The amount of energy

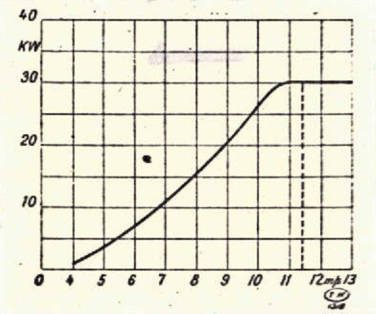

Figure 5. Eighteen-meter Lykkegaard aeromotor. Variation of power developed with wind velocity

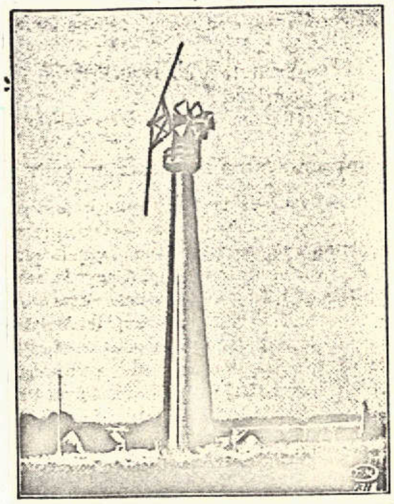

Figure 6. F.L.S. aeromotor 17.5 m in diameter mounted on concrete tower 24 m high.

Power: 50 kW for wind velocity of 10 m/sec

produced depends strongly on local conditions. It can be as much as 50,000 kWh per year for an 18 m mill. The highest daily value recorded was 600 kWh. This corresponds to an average power of 25 kW.

The Lykkegaard mills are very strongly constructed. Maintenance is very low, and generally limited to inspection of the mechanical parts every two weeks. The price of an 18 m mill, complete with a 20 m pylon and the mechanical transmission, was 10,930 Danish kroner in 1939. This price should have increased by 70% by now.

The F.L.S. aeromotors constructed by the Smidth company also operate in parallel with a bank of storage batteries. They are of more modern design, with two narrow blades (Figure 6), and are characterized chiefly by a high u/v ratio, where u is the circumferential velocity of the blade tips and v is the wind velocity. This ratio reaches 9, instead of the 2.5 of the Lykkegaard mills. The increased rotational velocity reduces the size and mass of the blades, and decreases the size of the gear train between the wheel and the generator. It does, however, have the drawback of reducing the torque available for starting, and measures have had to be taken to remedy this.

The blades are constructed of special lacquered wood, and their leading edges are protected by sheet-metal facings. They slant toward the rear, in the direction of the resultant of the centrifugal force and the wind pressure, so that they work almost entirely in tension. The speed governor consists of a narrow flap running the length of the blade, and normally retracted within it. When the intended maximum rotational speed is reached, a centrifugally-activated system moves the flap out of the blade; its braking action in the air is sufficient to prevent further increase in velocity. A mechanical brake is also provided to hold the mill once it has stopped.

The orientation of the mill about the pylon head is obtained — as with the Lykkegaard mills — with the aid of two small six-bladed mills geared to a circular rack gear.

The F.L.S. mill does not have sufficient torque to start, and thus cannot start by itself. It must be started either by a starting motor, or by the generator powered by the batteries and acting as a motor. As soon as the mill reaches a certain speed, it begins to supply power and the starting motor acts as a generator. This starting can be achieved automatically, with the brake released and the air-brake flap retracted, by means of a small mill placed at the tip of the pylon which closes a contact when the wind velocity reaches a definite value sufficient to operate the aeromotor. A safety device activates

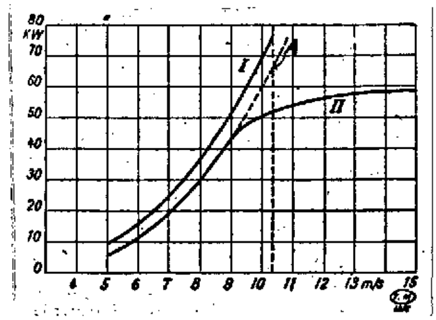

Figure 7. F.L.S. aeromotor 17.5 m in diameter. Variation of power developed with wind velocity.

I. Maximum power obtainable from the wind; II. Power from the aeromotor; A- Theoretical value for 10.2 m/sec not achieved

the mechanical brake when the wind suddenly blows hard from the rear of the wheel after a period of calm, and would otherwise rotate it in the wrong direction.

The dynamo is placed at the top of the pylon, to avoid the problems inherent in a long vertical shaft. It has special exciting windings for better adaptation to variations in wheel velocity. In an installation feeding an AC grid, the dynamo supplies the motor of a converter so that the aeromotor can turn at variable speed.

F. L. S. aeromotors are generally mounted on metal pylons. Because of the steel shortage, they have sometimes been mounted on circular concrete towers with interior stairways which makes inspection of the mechanism easier and less dangerous, especially in winter.

These aeromotors begin to supply current when the wind velocity is 5 m/s. Their nominal power of 50 kW is reached at a velocity of 10 m/s (Figure 7). The generator can be /109 overloaded, however, and 70 kW can be obtained from a 17.5 m aeromotor. There are not yet sufficient data on the annual energy which they can produce. The value of 2-300,000 kWh, which had been counted on at the outset, has been conceded to be too high. This error is due, as we shall see below, to inexact reports of wind frequencies. Be that as it may, daily outputs of 1400 kWh can be obtained, corresponding to an average power of 57.5 kW.

The approximate price of an F.L.S. installation, 17.5 m in diameter, complete except for batteries, is about 55,000 Danish kroner.

Besides these relatively large installations, there are also in Denmark a large number of independent low-power installations, intended principally for lighting isolated farms. These have a two- or three-bladed wheel, 2 to 3 meters in diameter, connected directly to a low-speed dynamo. The voltage varies from 6 to 220 V, depending on the installation, and the power from 125 to 1000 W. The battery consists of a number of automobile cells. Such a system is generally insufficient to provide lighting during prolonged periods of calm. There is then no lighting. A back-up system, which could consist of little more than a producer-gas engine, can not be expected for such small installations.

REFERENCES

1. Stein, Dimitry. Elektrizitaetswirtschaft. 5 and 20 August, 1942. See also La Technique Moderne, Vol. 34, No. 19 and 20, 1 and 15 October, 1942, p. 203.

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108.